US009082958B2

(12) **United States Patent**
Lu et al.

(10) **Patent No.: US 9,082,958 B2**
(45) **Date of Patent: Jul. 14, 2015**

(54) **TUNNELING MAGNETO-RESISTIVE SENSORS WITH BUFFER LAYERS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/568,645**

(22) Filed: **Dec. 12, 2014**

(65) **Prior Publication Data**

US 2015/0097255 A1 Apr. 9, 2015

Related U.S. Application Data

(63) Continuation of application No. 13/152,860, filed on Jun. 3, 2011, now Pat. No. 8,922,956.

(60) Provisional application No. 61/351,788, filed on Jun. 4, 2010.

(51) **Int. Cl.**
G11B 5/39 (2006.01)
H01L 43/08 (2006.01)
H01L 43/02 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 43/08*** (2013.01); ***G11B 5/3909*** (2013.01); ***H01L 43/02*** (2013.01); *G11B 2005/3996* (2013.01)

(58) **Field of Classification Search**
CPC H01L 43/08; H01L 43/02; G11B 5/3909; G11B 5/3903; G11B 2005/3996; G11B 5/3143; G11B 5/313; G01R 33/098
USPC 360/319, 324–324.2
See application file for complete search history.

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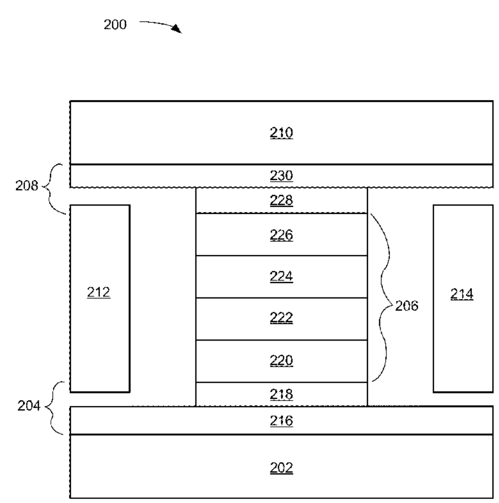
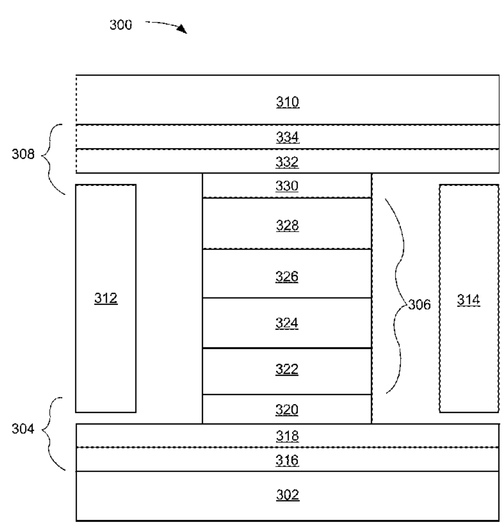
(57) **ABSTRACT**

In certain embodiments, a tunneling magneto-resistive (TMR) sensor includes a sensor stack positioned between a seed layer and a cap layer. The seed layer includes a first buffer layer that includes a non-magnetic nickel alloy. In certain embodiments, a sensor stack includes a top and bottom shield and a seed layer positioned adjacent to the bottom shield. The seed layer has a first buffer layer that includes a nickel alloy.

18 Claims, 3 Drawing Sheets





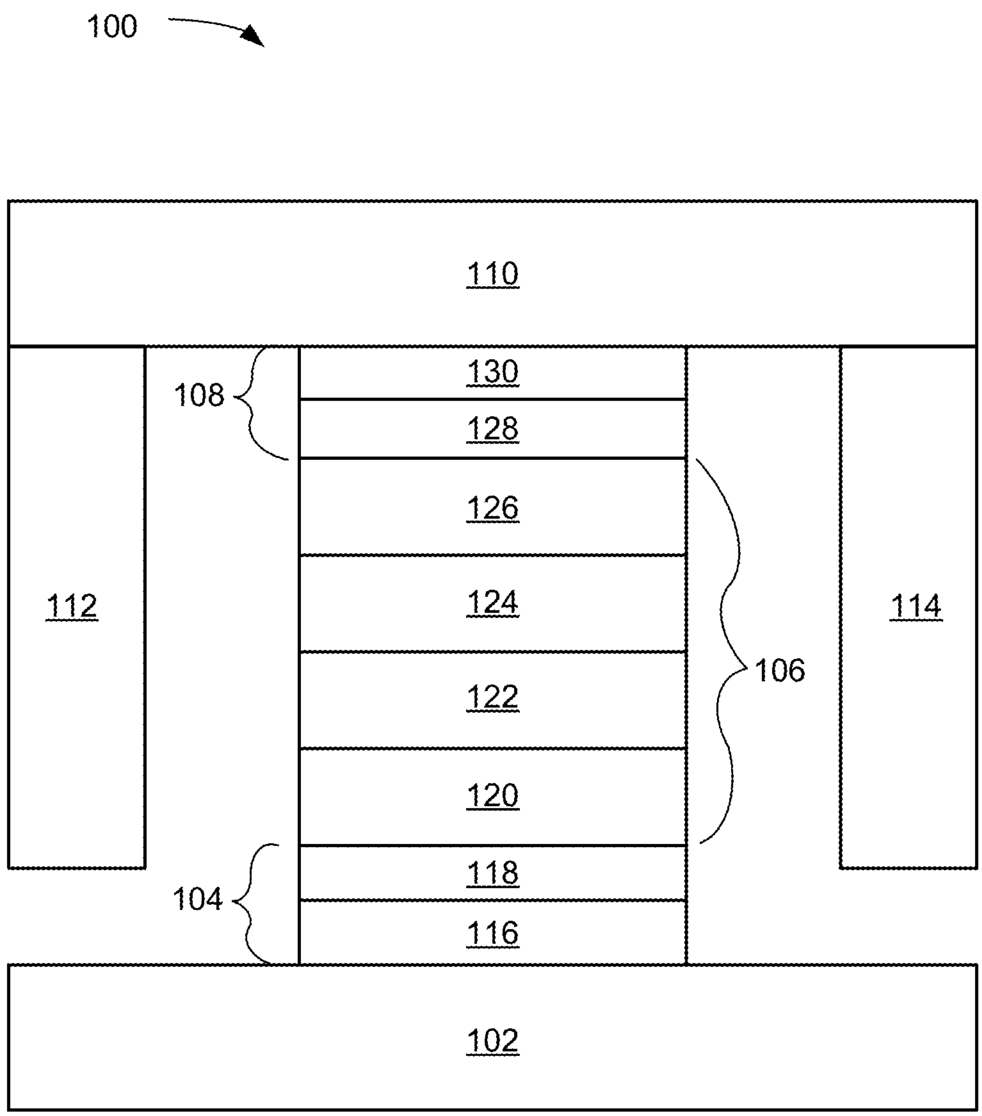


FIG. 1

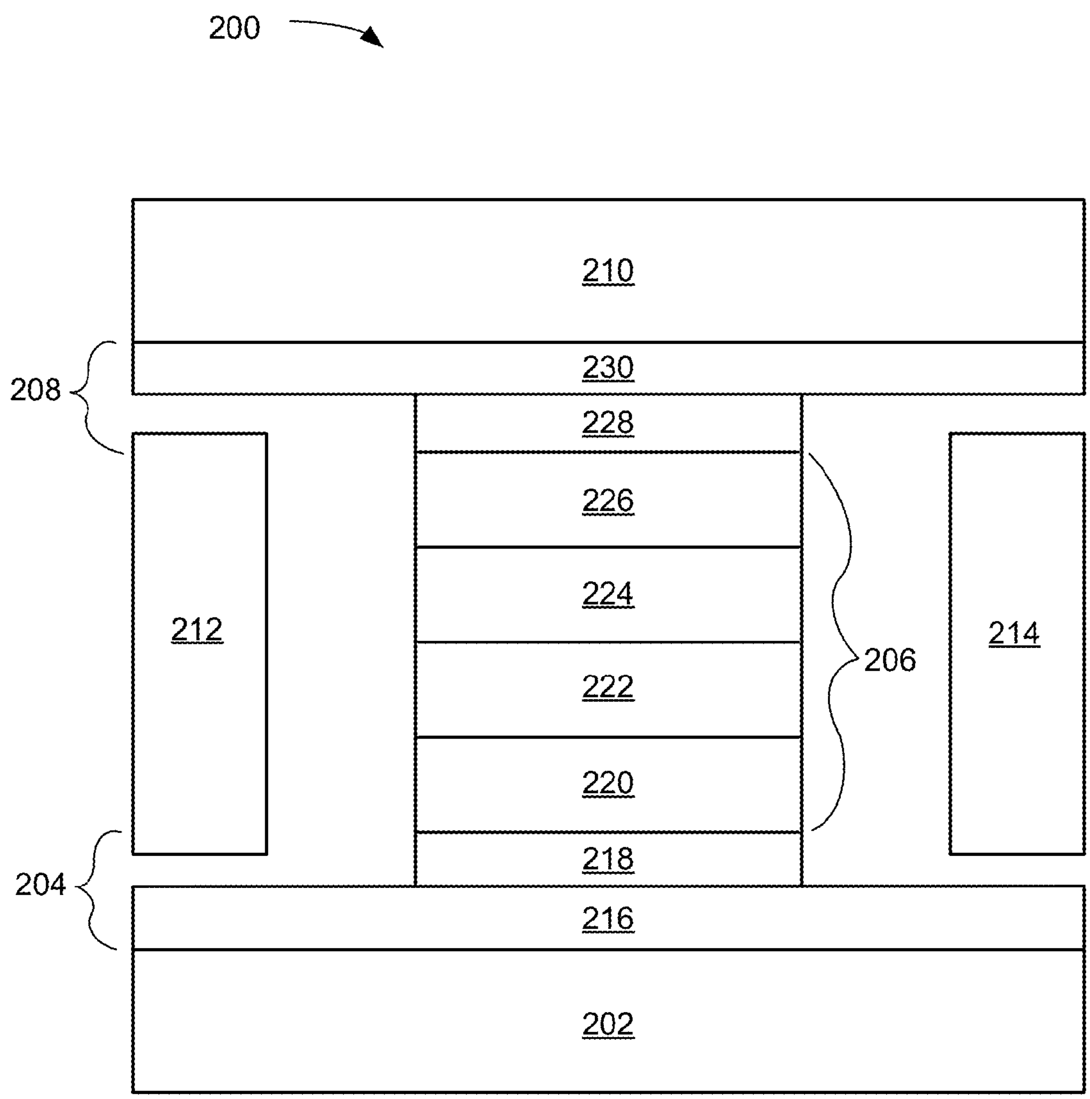


FIG. 2

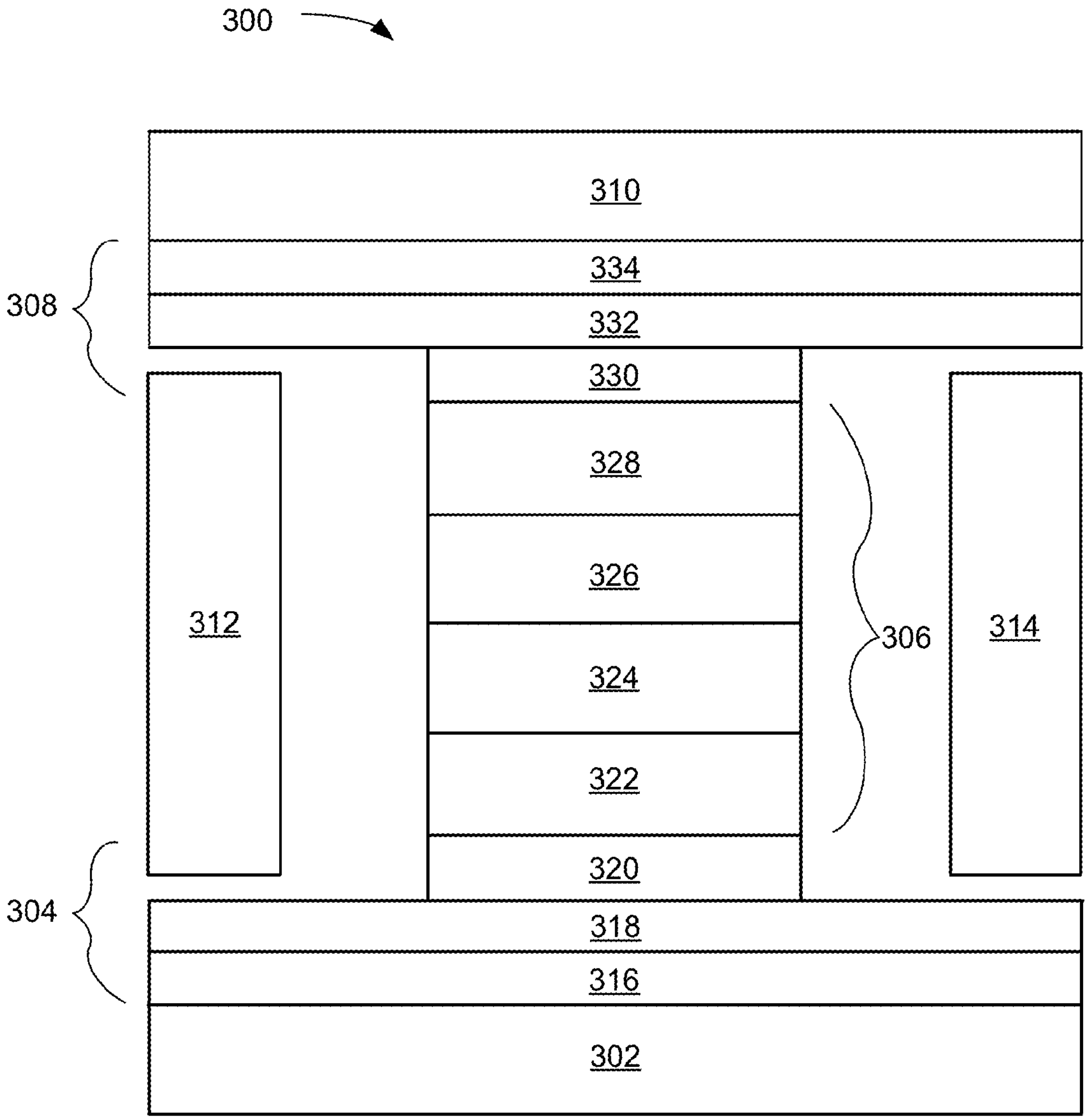

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FIG. 3

TUNNELING MAGNETO-RESISTIVE SENSORS WITH BUFFER LAYERS

RELATED APPLICATIONS

This application is a continuation application of U.S. application Ser. No. 13/152,860, filed Jun. 3, 2011, which claims priority to U.S. Provisional Application No. 61/351,788 filed Jun. 4, 2010, the contents of which are incorporated herein by reference thereto in their entirety.

SUMMARY

Certain embodiments of the present invention are generally directed to devices that include a tunneling magneto-resistive (TMR) sensor having multiple buffer layers.

In certain embodiments, a tunneling magneto-resistive (TMR) sensor includes a sensor stack positioned between a seed layer and a cap layer. The seed layer includes a first buffer layer that includes a nickel alloy.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** provides a side view of an exemplary tunneling magneto-resistive sensor, in accordance with certain embodiments of the present disclosure.

FIG. **2** provides a side view of an exemplary tunneling magneto-resistive sensor, in accordance with certain embodiments of the present disclosure.

FIG. **3** provides a side view of an exemplary tunneling magneto-resistive sensor, in accordance with certain embodiments of the present disclosure.

DETAILED DESCRIPTION

The present disclosure relates to buffer layers and shields for use in tunneling magneto-resistive (TMR) sensors.

Data storage devices, such as hard disk drives, can be provisioned with a magnetic recording head and a rotatable medium to which data are stored. As track density increases, the size of read sensors in magnetic heads is reduced because the bit size of the media being read is reduced. For example, at 1 Tb/in^2 and a bit aspect ratio of 4, the bit size in the media is about 12.5 nm by 50 nm.

When the media is being read (i.e. a playback process), a read sensor's signal-to-noise-ratio (SNR) and resolution can contribute to playback errors. To improve the read sensor's resolution, the read sensor's shield-to-shield-spacing (SSS) can be reduced. Further, controlling certain read sensor material characteristics, like orientation and roughness, can also be used to improve read sensor performance and overall SNR. Moreover, for TMR sensors having anti-ferromagnetic (AFM) layers, improvements can be achieved by varying AFM layer's ordering and magnetic dispersion as well as its indirect impact on subsequent layers, such as insulating tunnel barriers.

Certain embodiments of the present disclosure are accordingly directed to devices and methods for providing a tunneling-magneto resistive (TMR) sensor with controlled grain orientation and reduced shield-to-shield spacing, material roughness, and grain size.

FIG. **1** provides a tunneling magneto-resistive (TMR) sensor **100** including a bottom shield **102**, seed layer **104**, sensor stack **106**, cap layer **108**, top shield **110**, and permanent magnets **112**, **114**. The seed layer **104** includes a first and second seed buffer layer **116**, **118**. The sensor stack **106** can include, but is not limited to, an anti-ferromagnetic (AFM) layer **120**, synthetic anti-ferromagnetic (SAF) layer **122**, barrier layer **124**, and free layer **126**. The cap layer **108** includes a first and second cap buffer layer **128**, **130**. Certain spacing and insulating layers of the TMR sensor **100** may be omitted for clarity. Further, layers may not be to scale.

As shown in FIG. **1**, the sensor stack **106** is positioned between the bottom shield **102** and the top shield **110**, both of which include a crystalline layer comprising nickel-iron (NiFe). In FIG. **1**, the first seed buffer layer **116** includes an amorphous layer comprising a chromium-tantalum (CrTa) alloy, for example $CrTa_{40}$. The second seed buffer layer **118** includes a crystalline layer comprising a non-magnetic nickel alloy. The non-magnetic nickel alloy, nickel-tungsten, can include metal additives, for example, NiW_xY (where x=0-20 atm %) and Y stands for metal additives, such as Cr, Zn, Ti, Nb, Fe, Al, Co. These non-magnetic nickel alloys can result in the AFM layer **120** having good <111> orientation. Further, when adjacent to a non-magnetic nickel alloy, the AFM layer **120** can have a full width at half maximum (FWHM) of an x-ray rocking curve equal to 5 degrees or less. Further yet, the crystalline second seed buffer layer **118** provides the seed layer **104** with an orientation of a hexagonal-closed-packed (hcp) or face-centered-cubic (fcc) lattice structure with a <0002> or <111> growth orientation, so that the AFM layer **120** can have a good epitaxy and columnar growth instead of V-shaped growth. As a result the AFM layer **120** could have a small grain size with good orientation and low roughness.

The first seed buffer layer **116** provides a smooth, wetted surface for the second seed buffer layer **118** to grow into a controlled orientation, for example, having a hexagonal-closed-packed (hcp) or face-centered-cubic (fcc) lattice structure with a <0002> or <111> growth orientation, respectively. As a result, the adjacent AFM layer **120** could likewise have a controlled orientation and columnar and small grain size, for example, a hexagonal-closed-packed (hcp) or face-centered-cubic (fcc) lattice structure with a <0002> or <111> growth orientation, respectively.

The first and second cap buffer layers **128**, **130** can include the same materials as the first and second seed buffer layers **116**, **118**, but stacked in reverse order. Certain buffer layers can have a thickness of 1 nanometer or less.

FIG. **2** provides a tunneling magneto-resistive (TMR) sensor **200** including a bottom shield **202**, seed layer **204**, sensor stack **206**, cap layer **208**, top shield **210**, and permanent magnets **212**, **214**. The seed layer **204** includes a first and second seed buffer layer **216**, **218**. The sensor stack **206** can include, but is not limited to, an anti-ferromagnetic (AFM) layer **220**, synthetic anti-ferromagnetic (SAF) layer **222**, barrier layer **224**, and free layer **226**. The cap layer **208** includes a first and second cap buffer layer **228**, **230**. The side shields **212**, **214** are permanent magnets. Certain spacing and insulating layers of the TMR sensor **200** may be omitted for clarity. Further, layers may not be to scale.

In FIG. **2**, the first seed buffer layer **216** can include an amorphous magnetic alloy, for example a Ni-, Fe-, or Co-alloy, like FeCoZrTa or FeCoB. Further, the amorphous magnetic alloy can include amorphous additives, for example B, Zr, Ta, or Hf. The second seed buffer **218** can include a crystalline layer comprising a non-magnetic nickel alloy, for example nickel-tungsten (NiW_8). Alternatively, in certain embodiments, the seed buffer layers can include a magnetic nickel alloy like NiFeW and Ruthenium (Ru). The bottom shield **202** and the top shield **210** include a crystalline layer comprising nickel-iron. The first and second cap buffer layers **228**, **230** include the same materials as the respective first and second seed buffer layers **216**, **218**, but stacked in reverse order. Certain buffer layers (e.g., the second seed buffer **218** and the first cap buffer layer **228**) can have a thickness of 1 nanometer or less.

Because the first seed buffer layer **216** and the second cap buffer layer **230** are magnetic (e.g., an amorphous magnetic alloy), those layers can be considered to be made part of or act as part of the bottom shield **202** and top shield **210**, respectively. Put another way, the first seed buffer layer **216** and/or the second cap buffer layer **230** can effectively act or perform as a magnetic buffer and a magnetic shield. As a result, shield-to-shield spacing is reduced. Moreover, this arrangement of materials would permit the thickness of the first seed buffer layer **216** and the second cap buffer layer **230** to be made thicker, resulting in reduced design constraints and controlled orientation of the second seed buffer layer **218** and the first cap buffer layer **228**.

FIG. **3** provides a tunneling magneto-resistive (TMR) sensor **300** including a bottom shield **302**, seed layer **304**, sensor stack **306**, cap layer **308**, top shield **310**, and permanent magnets **312**, **314**. The seed layer **304** includes a first, second, and third seed buffer layer **316**, **318**, **320**. The sensor stack **106** can include, but is not limited to, an anti-ferromagnetic (AFM) layer **322**, synthetic anti-ferromagnetic (SAF) layer **324**, barrier layer **326**, and free layer **328**. The cap layer **308** includes a first, second, and third cap buffer layer **330**, **332**, **334**. The side shields **312**, **314** are permanent magnets. Certain spacing and insulating layers of the TMR sensor **300** may be omitted for clarity. Further, layers may not be to scale.

In FIG. **3**, the first seed buffer layer **316** includes an amorphous magnetic alloy, for example a Ni-, Fe-, or Co-alloy, like FeCoZrTa. The second seed buffer layer **318** includes a crystalline layer comprising a nickel alloy having a magnetic moment, for example $NiFe_{20}$. Further, the crystalline layer could also include Ni-alloys with other magnetic elements, for example, $NiFe_xY$ (where x=0-50 atm %) and where Y stands for metal additives such as Cr, Zn, Ti, Nb, Fe, Al, or Co.

The third seed buffer **320** includes a crystalline layer comprising a non-magnetic nickel alloy, for example NiW_8. The bottom shield **302** and the top shield **310** can include a crystalline layer comprising nickel-iron. The first, second, and third cap buffer layers **330**, **332**, **334** include the same materials as the first, second, and third seed buffer layers **316**, **318**, **320**, but stacked in reverse order. Certain buffer layers (e.g, the third seed buffer **320** and the first cap buffer layer **330**) can have a thickness of 1 nanometer or less.

Because the first and second seed buffer layers **316**, **318** and the second and third cap buffer layers **332**, **334** are magnetic, those layers can be considered or act as part of the bottom shield **302** and top shield **310**, respectively. As a result, shield-to-shield spacing is reduced. Moreover, this arrangement of materials would permit the thickness of the first and second seed buffer layers **316**, **318** and the second and third cap buffer layers **332**, **334** to be made thicker, resulting in reduced design constraints and controlled orientation of the third seed buffer layer **320** and the first cap buffer layer **334**. For example, the thickness of the second seed buffer layer **318** could be 5 nanometers or thicker.

The bottom and top shields **302**, **310** can alternatively include an amorphous magnetic alloy, for example a Ni-, Fe-, or Co-alloy, like FeCoZrTa and FeCoB. Further, the amorphous magnetic alloy can include amorphous additives, for example B, Zr, Ta, or Hf Amorphous magnetic alloys are smooth (or have a low surface roughness) and by using amorphous magnetic alloys for the bottom and top shields **302**, **310**, certain manufacturing steps can be eliminated, for example certain steps of electroplating and chemical mechanical polishing (CMP) could be skipped, thereby increasing overall manufacturing yield and efficiency for the TMR sensor **300**.

It is to be understood that even though numerous characteristics and advantages of various embodiments of the present invention have been set forth in the foregoing description, together with details of the structure and function of various embodiments of the invention, this detailed description is illustrative only, and changes may be made in detail, especially in matters of structure and arrangements of parts within the principles of the present invention to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed.

What is claimed is:

1. A tunneling magneto-resistive (TMR) sensor comprising:
- a seed layer comprising a first seed buffer layer and a second seed buffer layer,
  - the first seed buffer layer comprising an amorphous magnetic alloy and the second seed buffer layer comprising a non-magnetic nickel alloy or a magnetic nickel alloy;
- a cap layer comprising a first cap buffer layer and a second cap buffer layer,
  - the first cap buffer layer comprising a non-magnetic or a magnetic nickel alloy and the second cap buffer layer comprising an amorphous magnetic alloy; and
- a sensor stack positioned between the seed layer and the cap layer, wherein the second seed buffer layer and the first cap buffer layer are adjacent the sensor stack.

2. The TMR sensor according to claim **1**, wherein the first seed buffer layer and the second cap buffer layer independently further comprise B, Zr, Ta, or Hf.

3. The TMR sensor according to claim **1**, wherein the first seed buffer layer and the second cap buffer layer comprise NiFeW.

4. The TMR sensor according to claim **1**, wherein the first seed buffer layer and the second cap buffer layer independently comprise FeCoZrTa or FeCoB.

5. The TMR sensor according to claim **1**, wherein the second seed buffer layer and the first cap buffer layer independently comprise a non-magnetic nickel alloy.

6. The TMR sensor according to claim **5**, wherein the second seed buffer layer and the first cap buffer layer comprise NiW_8.

7. The TMR sensor according to claim **1**, wherein the second seed buffer layer and the first cap buffer layer independently comprise a magnetic nickel alloy.

8. The TMR sensor according to claim **7**, wherein the second seed buffer layer and the first cap buffer layer independently comprise $NiFe_xY$, where x is 0-50, and Y is selected from Cr, Zn, Ti, Nb, Fe, Al, or Co.

9. The TMR sensor according to claim **7**, wherein the second seed buffer layer and the first cap buffer layer comprise NiFeW.

10. A device comprising:
- a seed layer comprising a first seed buffer layer and a second seed buffer layer, the first seed buffer layer comprising an amorphous magnetic alloy and the second seed buffer layer comprising a non-magnetic or a magnetic nickel alloy;
- a cap layer comprising a first cap buffer layer and a second cap buffer layer, the first cap buffer layer comprising a non-magnetic or a magnetic nickel alloy and the second cap buffer layer comprising an amorphous magnetic alloy; and

a sensor stack positioned between the seed layer and the cap layer, wherein the second seed buffer layer and the first cap buffer layer are adjacent the sensor stack; and

a top and bottom shield, the bottom shield positioned adjacent the seed layer and the top shield positioned adjacent the cap layer.

11. The device according to claim **10**, wherein the first seed buffer layer and the second cap buffer layer independently comprise a Ni-, Fe-, or Co-alloy, the Ni, Fe-, or Co-alloy further comprising B, Zr, Ta, or Hf.

12. The device according to claim **10**, wherein the second seed buffer layer and the first cap buffer layer independently comprise a non-magnetic nickel alloy.

13. The device according to claim **12**, wherein the second seed buffer layer and the first cap buffer layer comprise NiW_8.

14. The device according to claim **10**, wherein the second seed buffer layer and the first cap buffer layer independently comprise a magnetic nickel alloy.

15. The device according to claim **14**, wherein the second seed buffer layer and the first cap buffer layer independently comprise $NiFe_xY$, where x is 0-50, and Y is selected from Cr, Zn, Ti, Nb, Fe, Al, or Co.

16. The device according to claim **14**, wherein the second seed buffer layer and the first cap buffer layer comprise NiFeW.

17. A tunneling magneto-resistive (TMR) sensor comprising:

a seed layer comprising a first seed buffer layer and a second seed buffer layer,

the first seed buffer layer comprising an amorphous magnetic Ni-, Fe-, or Co-alloy and the second seed buffer layer comprising a non-magnetic nickel alloy or a magnetic nickel alloy;

a cap layer comprising a first cap buffer layer and a second cap buffer layer,

the first cap buffer layer comprising a non-magnetic or a magnetic nickel alloy and the second cap buffer layer comprising an amorphous magnetic Ni-, Fe-, or Co-alloy; and

a sensor stack positioned between the seed layer and the cap layer, wherein the second seed buffer layer and the first cap buffer layer are adjacent the sensor stack.

18. The TMR sensor according to claim **17**, wherein the first seed buffer layer and the second cap buffer layer comprise NiFeW, and the second seed buffer layer and the first cap buffer layer independently comprise NiW_8 or NiFeW.

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